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U1S S2204 S2214

(56) Documents Cited
GB 2281008 A GB 2250153 A GB 2160735 A
GB 1505434 A WO 96/04155 A1 WO 93/12590 A1
WO 88/09140 A1 US 5465289 A US 5218367 A
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INT CL[6] G01S, H04Q
Online:- WPI, EDOC

(54) Direction-finding for cellular radio

(57) The direction to a cellular telephone handset from a base station is determined at the base station by an antenna system having two or more independent radiation patterns. The radiation patterns of the antennas differ in a known manner. The power differential between the received signals is determined and compared with previously determined data representative of the spatial differences between the radiation patterns of the antennas to determine the direction of the handset relative to the base station. The different radiation patterns may be obtained by switching parasitic elements in and out (connecting or disconnecting a load) during, or between, pulse sequences. The range of the handset may be obtained from the received signal strength. Time-separated range and direction measurements may give the handset's speed, which may be used to control hand-over.

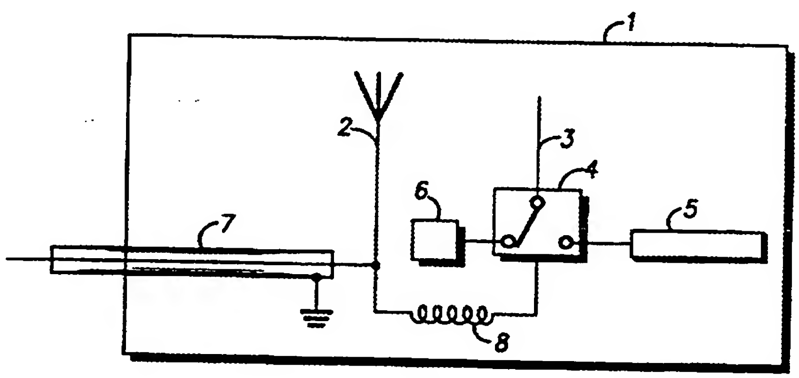

FIG.1

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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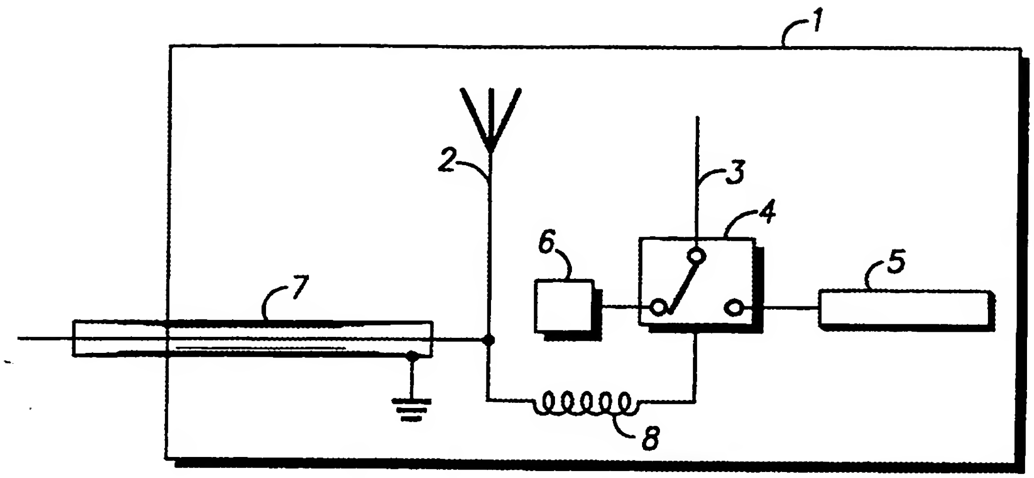


FIG.1

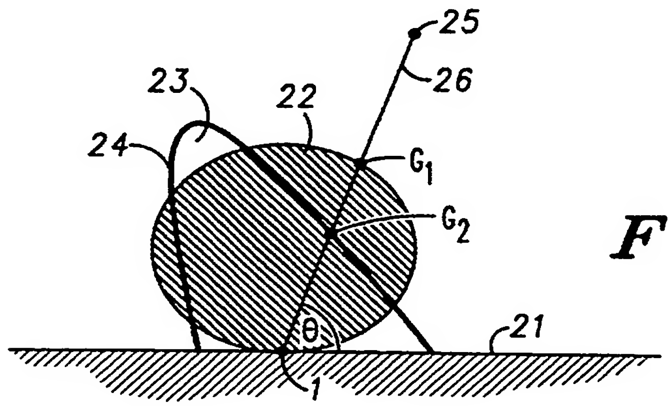


FIG.2A

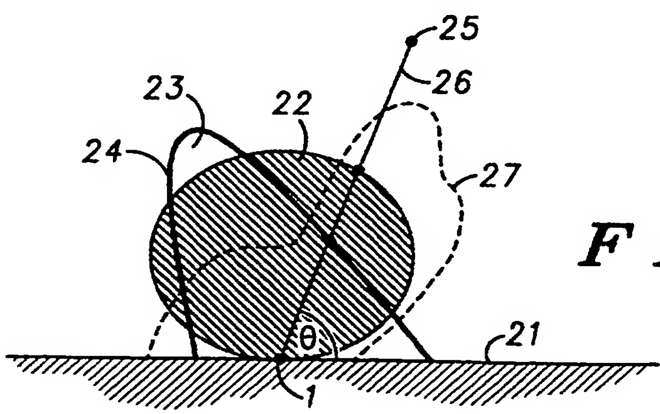
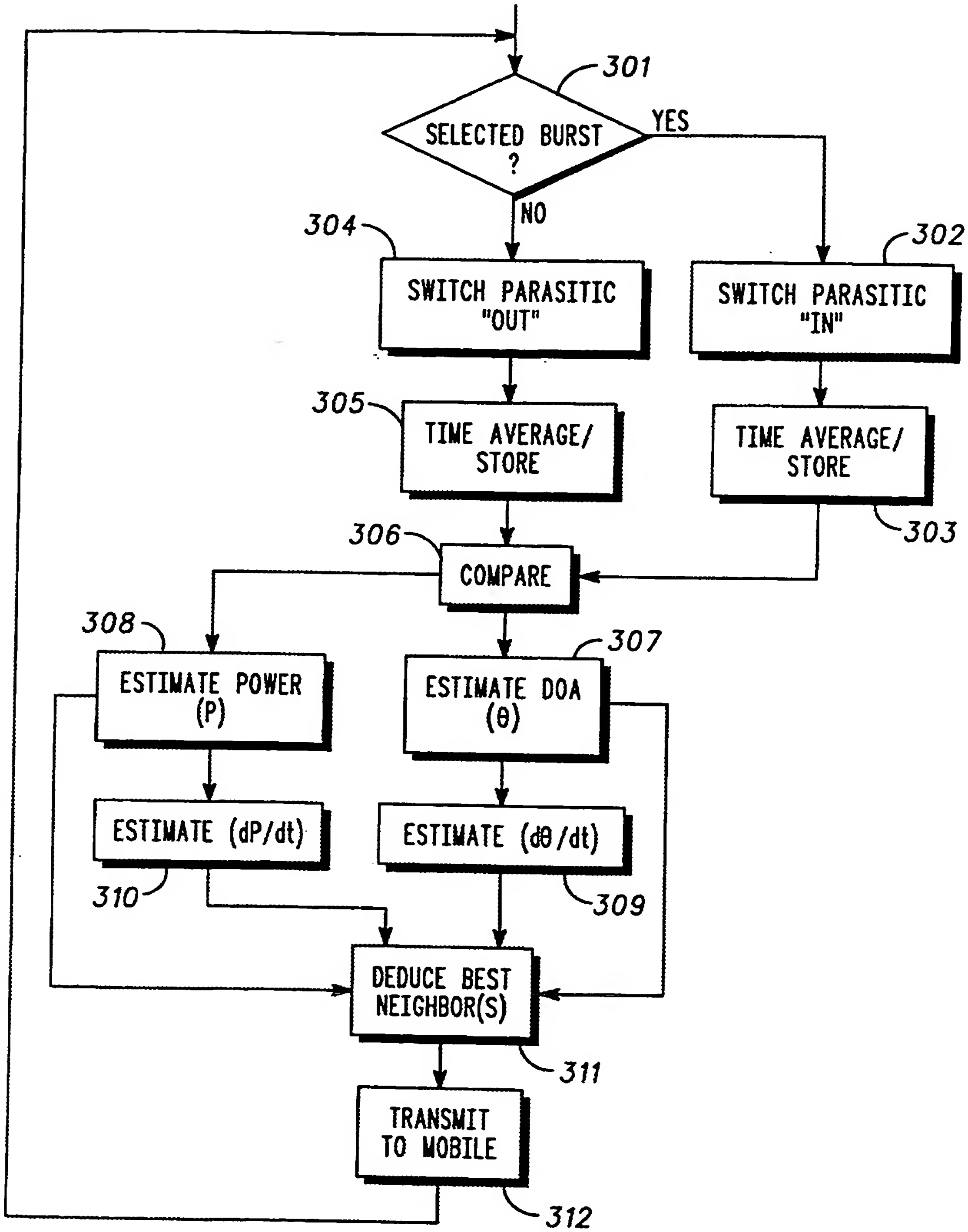


FIG.2B



301
SELECTED BURST ?
YES
NO
304
SWITCH PARASITIC "OUT"
302
SWITCH PARASITIC "IN"
305
TIME AVERAGE/ STORE
TIME AVERAGE/ STORE
303
306
COMPARE
308
ESTIMATE POWER (P)
307
ESTIMATE DOA (θ)
ESTIMATE (dP/dt)
ESTIMATE (dθ/dt)
310
309
DEDUCE BEST NEIGHBOR(S)
311
TRANSMIT TO MOBILE
312

FIG.3

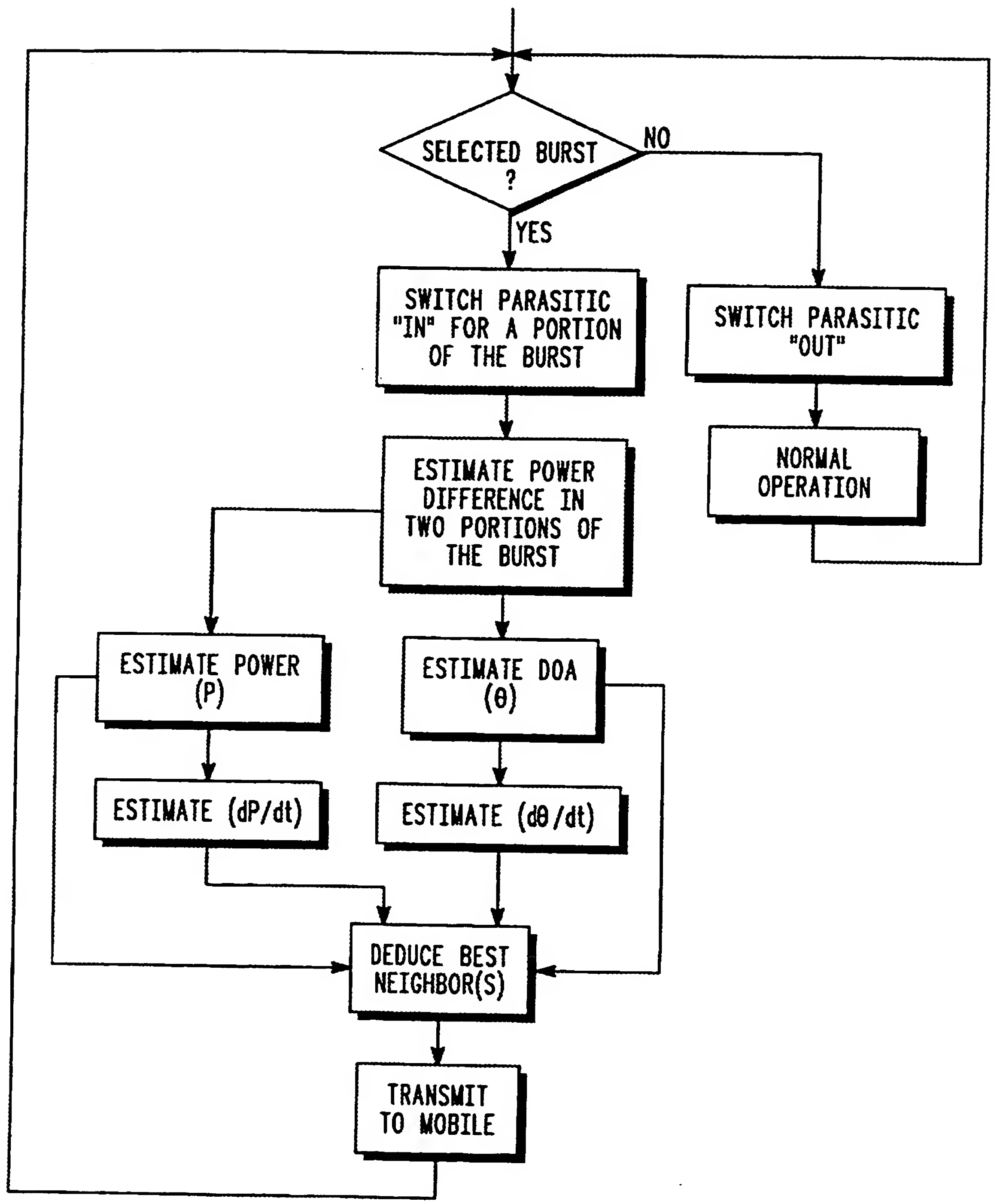

SELECTED BURST ?
NO
YES
SWITCH PARASITIC "IN" FOR A PORTION OF THE BURST
SWITCH PARASITIC "OUT"
NORMAL OPERATION
ESTIMATE POWER DIFFERENCE IN TWO PORTIONS OF THE BURST
ESTIMATE POWER (P)
ESTIMATE DOA (θ)
ESTIMATE (dP/dt)
ESTIMATE (dθ/dt)
DEDUCE BEST NEIGHBOR(S)
TRANSMIT TO MOBILE

FIG.4

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Radio Direction Finding

Field of the Invention

The present invention relates to radio direction finding, and more specifically, to radio direction finding techniques for use in microcell radio communication systems.

Background of Invention

The antennas used in microcell cellular mobile communication systems in an urban environment usually are placed below the tops of buildings surrounding the antennas, so that the effective range of the antennas is limited to about three hundred metres. A result of the low antenna height is that the predominant mode of propagation of radiation to and from the antennas is line-of-sight, with some contributions from reflection, scattering from buildings and diffraction at the corners of buildings. The areas of microcells which have line-of-sight communication with a mobile transceiver usually have high signal strengths and reduced multi-path fading. However, in an urban environment, a mobile station can lose line-of-sight communication with a base station merely by turning a corner, which results in a rapid decrease in the signal level and a reduction in the signal quality as a result of increased multi-path fading. Moreover, the signal degradation relative to a particular base station may be coupled with an increased signal from a neighbouring cell. If a mobile station is to be handed over successfully to a more appropriate cell, the hand-off process has to be sufficiently fast to react to sudden changes in signal levels and quality. This task is complicated further by the irregular pattern and large number of microcells in an urban environment, which means that there may be a large

number of possible neighbouring microcells which are potential candidates for a hand-off at any one time, so reducing the quality of measurements of the use of mobile stations in an environment where multi-path signal fading occurs.

The base station of a microcell in an urban environment may be situated some distance along a long street, or at a road junction. The management of the more complicated microcell structure where the base station is sited at a road junction, where each road may lead to a number of neighbouring microcell sites, can be assisted by prior knowledge of the identity of the road, and the direction of movement and the speed of a mobile station along that road. This information can help the hand-off algorithms to concentrate on the immediate neighbouring and umbrella cells along a given track for a mobile station. The required information can be derived from a knowledge of the direction from which signals arrive at a base station from a mobile station, together with the profile of the power gradient of the received signal and the rate of change of the signal strength.

Currently, there is no radio direction finding method which is suitable for use in connection with cellular radio communication systems. Existing radio direction finding techniques fall into two main categories; systems which use scanning antennas and systems which use arrays of fixed antennas which are "steered" by means of phased switching. The former are not practicable in the context of microcellular radio communication systems, and the latter are too expensive, as well as requiring antenna arrays which are too large for use in the context of cellular radio systems.

There are a number of hybrid techniques which are used for radar detection and tracking. These techniques use at least two antennas. The received signals are operated upon in sum and difference modes. In the active mode, the sum signal pattern is used to locate a target and determine its direction and in the passive mode the difference signal pattern is used to track the target. The tracking is performed by measuring an error signal resulting from the differential power signals derived from a plurality of similar directional antennas each of which has an orientation which differs slightly from those of the others. As highly directional antennas are required for the tracking function, the antennas are still large at the frequencies used for cellular radio communication. These hybrid radar techniques, therefore, also are not practicable for use in the field of cellular radio communication.

Summary of the Invention

The present invention provides a method of, and apparatus for, estimating the direction from which a signal from a mobile station is received at a base station.

The three-dimensional distribution, or radiation pattern, or energy radiated from an antenna is related to the form of the antenna and can be determined by calculation, or empirically. If the antenna is operated in a receiving, or passive, mode then the sensitivity has the same spatial form as the radiation pattern for the antenna in an active mode.

According to the present invention there is provided a method of estimating the direction of arrival at a base station of a radio signal, comprising the operations of determining the difference between the power level of

respective output signals produced in response to the radio signal by an antenna system situated at the base station the antenna system having at least two radiation patterns of which differ in a known fashion, and determining therefrom an estimate of the direction of arrival of the radio signal at the base station.

The comparison can be made between entire signal pulses, received at the base station by one antenna system or the other. Alternatively, one half of a signal pulse can be arranged to be received by one antenna system and the other half of the pulse by the other antenna system and the two received signal powers compared as before.

Preferably, the radio signal is a microcellular telecommunication signal and the signal pulses are the signal bursts transmitted by the mobile stations of such systems.

Also according to the present invention there is provided an apparatus for determining the direction from which a radio signal is received at a base station, comprising an antenna system situated at the base station, the antenna system having at least two radiation patterns which differ in a pre-determined fashion, means for measuring the difference between the power of the respective output signals produced by the antenna system utilising each of the independent radiation patterns separately in response to the radio signal and means for determining therefrom an estimation of the direction from which the radio signal originated.

It is not necessary to have antennas which are different physically, the difference can be achieved electrically by altering the electrical characteristics of a single physical entity, which may be made up of a number

of elements. For example, there may be a single active element and one or more parasitic elements, which are switched between a dormant and an active state.

An example of such an antenna is a Yagi type antenna consisting of a dipole and one or more parasitic director or reflector elements. In one state the parasitic element or elements are connected to a matched load so as to render it, or them, dormant, and in the other state are connected to either open or short circuit terminations.

With such an arrangement, the received power is determined with just the active antenna element, used in a receiving mode, then with the parasitic element, or elements operative. One received signal is compared with the other and the received signal power differential is determined. The received signal power differential is normalised against the power received by the active element only and the result is compared with previously determined normalised values of the received power differential for a known distribution of signals received by the same system of antennas, so as to provide an indication of the direction from which the signals are received by the base station.

If the transmitted signal power is known, then the received signal strength provides a measure of the distance between the transmitting station and the base station. This information, coupled with the estimated direction of arrival of the radio signals provides an estimate of the polar co-ordinates of the transmitting station. Moreover, the direction of the gradient of the received signal power indicates the direction of the line-of-sight component of the velocity of the mobile station relative to the base station, and the magnitude of the gradient of the received power provides a measure of the magnitude of the line-of-

sight component of the velocity of the mobile station relative to the base station.

In a situation where the mobile station is moving transversely of the line-of-sight direction between the mobile station and the base station, then the angular rate of change of the determined direction of receipt of the signals from the mobile station by the base station provides a measure of the transverse component of velocity of the mobile station.

The necessary computations for the above determinations can be carried out by means of dedicated microprocessors or by the use of neural networks which are trained on standardised situations.

Brief Description of the Drawings

The invention will now be described, by way of example, with reference to the accompanying drawings, in which

Figure 1 shows diagrammatically an antenna system which can be used to carry out the present invention,

Figure 2(a) illustrates the radiation patterns for the antenna system of Figure 1 with only the active element in use and with a single parasitic element in use,

Figure 2(b) illustrates similar radiation patterns for an antenna system which uses two parasitic elements.

Figure 3 shows a process flow diagram for a determination of the most suitable neighbouring base station, to an existing base station for a moving mobile station, and

Figure 4 shows a process flow diagram for a second method for determining of the most suitable neighbouring base station to an existing base station for a moving mobile station.

Description of a Preferred Embodiment

Referring to Figure 1, an antenna unit 1 which can be used to carry out the present invention consists of an active element 2 and a parasitic element 3. An electronic switch 4 is arranged to connect the parasitic element 3 to a matched load 5 or a short circuit, or open circuit termination 6. A suitable form of electronic switch is a GaAsFET device. A transmission line 7 connects the active element 2 of the antenna unit to the transceiver unit of a microcellular radio communication system base station (which is not shown in the figure). The transmission line 7 also is used to supply the operating signal to the electronic switch 4 via an inductive coupling 8. A separate control signal generator for the switch 4 can be used if desired.

Referring to Figure 2(a) the antenna unit 1 is shown mounted on a non-conducting planar surface 21. The shaded area 22 shows the radiation pattern of the antenna unit 1 when only the active element 2 is operational and the area 23 delineated by the line 24 shows the radiation pattern of the antenna unit 1 when the parasitic element 3 is operational also. In a normal transaction between the base station 1 and a mobile station 25, only the active element 2 of the antenna unit 1 is used and the passive element 3 is connected to the matched load 5. If it is desired to find the bearing θ of the mobile station 25 relative to the base station 1, then the parasitic element 3 of the antenna unit 1 is made operational by connecting it to the other

termination by means of the switch 5. The radiation pattern of the antenna unit 1 then changes from the symmetrical area 22 to the asymmetrical area 23. An incoming signal 26 from the mobile station 25 crosses the boundaries of the areas 22 and 23 at points G_1 and G_2, respectively. The power level of the output signals from the antenna unit 1 can be represented graphically as a function of the distances of the points G_1 and G_2 from the antenna unit 1. As can be seen from Figure 2(a), their algebraic difference is related to the angle θ and hence the direction of the mobile station 25 relative to the antenna unit 1 can be determined. It is to be noted that with a single parasitic element 3, more than one direction of arrival of the incoming signal 26 will produce the same differential power signal. In practice, this may not be important because the geometry of the site of the antenna unit 1 may be such that only a single direction of arrival of the incoming signal 26 is possible. If, however, further discrimination is required, then an antenna unit with more than one parasitic element can be used. Figure 2(b), for example shows the radiation patterns for an antenna unit which has a single active element, one parasitic element operational, as for Figure 2(a), and two parasitic elements operational, the latter state being shown by the dotted line 27.

It can be seen that, by switching from a one parasitic element state to a two parasitic element state, most of the regions of ambiguity in the determination of the direction of arrival of the signal 26 are removed. If necessary, the process can be repeated with more parasitic elements operational.

Figure 3 shows a flow diagram illustrating the sequence of steps followed in an operation for determining

to which neighbouring base station a moving mobile station should be handed over.

From the sequence of signal pulses, or bursts, transmitted from the mobile station to the base station a burst is selected (301) to be received when the parasitic element (302), of the antenna unit is operational. The term 'parasitic element' includes the case when more than one such element is present.

The power received by the antenna unit of the base station is measured and averaged over the duration of the burst and this parameter is stored (303). The same thing is done for a burst when only the active element of the antenna unit is operative in the receiving mode (305, 305). The two mean power signals are then compared (306) and the difference between them is determined and preferably normalised against the mean received power when only the active element of the antenna unit is operative. The normalised differential power parameter is used to estimate the direction of arrival of the signal from the mobile station (Ø) (307). The total power P received by the antenna unit with only the active element is measured and used to estimate the distance between the mobile station and the base station (308). The rate of change of the parameters Ø and P are derived and used to estimate the direction and speed of the motion of the mobile station relative to the base station (309, 310 respectively). The four parameters Ø, P, dØ/dt and dP/dt are used to deduce which is the most appropriate base station to which the mobile station should be handed over (311), the handover sequence is initiated and the appropriate signals are transmitted to the mobile station (312). The necessary computations can be carried out by means of a dedicated microprocessor, or by neural networks which are trained using known situations.

Figure 4 illustrates another process for carrying out the same operation but in this case, the parasitic element, of the antenna unit is made operative over a portion of the selected burst (401) from the mobile station (402) and one portion of the burst is compared with the other (403). The remaining steps of the operation are as before except that there is no separate determination and storage of the received signal power differentials for the two states of the antenna unit. The same reference numbers are used therefore. For the remainder of the time, the parasitic element is rendered inoperative (404) and the base station operates in the normal way (405).

In normal circumstances, with cellular radio communications set up under the auspices of the body known as group special mobile (GSM), when a system is being set up, each base station is programmed with a list of the positions of the best neighbouring base stations. Circumstances may change, so that the original listing is not appropriate.

An advantage of the present invention is that this fixed listing is not necessary, because the most appropriate base station for handover is chosen dynamically by the system, as required.

Claims

1. A method of estimating the direction of arrival at a base station of a radio signal, comprising the operations of determining the difference between the power level of respective output signals produced in response to the radio signal by an antenna system situated at the base station the antenna system having at least two radiation patterns which differ in a known fashion, and determining therefrom an estimate of the direction of arrival of the radio signal at the base station.

2. A method according to Claim 1 wherein there is included the operations of producing a difference signal related to the difference between respective output signals generated by the antenna systems in response to the radio signal using the independent radiation patterns sequentially, comparing the difference signal with data representative of the spatial difference between the radiation patterns of the antenna and deriving therefrom an estimate of the direction of the source of the radio signal relative to the base station.

3. A method according to Claim 1 or Claim 2 wherein there is included the operation of determining the distance of the source of the radiation signal from the base station.

4. A method according to Claim 3 wherein the source of the radio signal has a known power output, the absolute power of the radio signal received by the antenna system using one radiation pattern only is determined and the received power is compared with the transmitted power to provide an estimate of the distance between the source of the radio signal and the base station.

5. A method according to any of Claims 1 to 4 wherein there is included the operation of determining the direction of motion relative to the base station of the source of the radio signal.

6. A method according to Claim 5 wherein there is included the operation of determining the rate of motion relative to the base station of the source of the radio signal.

7. A method according to Claim 5 or Claim 6 wherein the direction and/or rate of motion relative to the base station of the source of the radio signal are determined by deriving the magnitude and sign of the rate of change of the power of the signal received by one antenna system.

8. A method according to any of Claims 1 to 7 wherein the radio signal is in the form of a sequence of signal pulses and there is included the operations of causing the antenna system to receive selected signal pulses, utilising one radiation pattern other signal pulses being received by the antenna system utilising another radiation pattern, producing respective output signals from the antenna system and determining the difference in the power levels of the two output signals from the antenna system.

9. A method according to any of Claims 1 to 7 wherein the radio signal is in the form of a sequence of signal pulses and there is included the operation of causing one antenna system to be operative in one mode during one part of a selected signal pulse and operative in a second mode during the other part of the signal pulse, producing respectively output signals from the antenna system and determining the difference in the power levels of the two output signals from the antenna system.

10. A method according to any preceding claim wherein the radio signal is generated by a mobile station forming part of a cellular radio communication system and there is included the operation of determining which base station neighbouring that at which the radio signal is received and also forming part of the cellular radio communication system is most appropriate to be linked to the base station.

11. A method according to Claim 10 wherein the operation of determining which base station neighbouring that at which the signal pulses are receiving from the mobile station is most appropriate to be linked to the base station is carried out by determining the distance of the mobile station from the base station, the direction and rate of motion relative to the base station of the mobile station and comparing these parameters with stored data relating to the positions of neighbouring base stations in the locality of the base station at which the signal pulses from the mobile station are received.

12. A method according to Claim 11 wherein the comparison is done by a microprocessor in which the data relating to the neighbouring base station is stored.

13. A method according to Claim 11 wherein the operation of determining which base station neighbouring that at which the signal pulses are received from the mobile station is carried out by a neural network.

14. A method according to Claim 13 wherein the neural network is trained by carrying out known movements of a test mobile station in the vicinity of the base station.

15. An apparatus for determining the direction from which a radio signal is received at a base station, comprising an

antenna system situated at the base station, the antenna system having at least two radiation patterns which differ in a pre-determined fashion, means for measuring the difference between the power of the respective signals produced by the antenna system utilsing each of the independent radiation patters separately in response to the radio signal and means for determining therefrom an estimation of the direction from which the radio signal originated.

16. An apparatus according to Claim 15 wherein the antenna system is constituted by a single physical entity and there is included means for varying the electrical characteristics of the single physical entity to form the independent radiation patterns.

17. An appratus according to Claim 16 wherein the single physical entity comprises an active element and one or more parasitic elements and there is included means for rendering the parasitic elements operative or inoperative thereby to provide the radiation patterns which differ in a pre-determined fashion.

18. An apparatus according to Claim 17 wherein the antenna system comprises a Yagi antenna having at least one director or reflector element.

19. An apparatus according to Claim 17 or Claim 18 wherein the means for rendering the parasitic elements operative or inoperative comprises an open or closed circuit termination for the parasitic element, a matched load for the parasitic element and a switch for connecting the parasitic element to the open or closed circuit termination to render the parasitic element operative or to the matched load to render the parasitic element inoperative.

20. An apparatus according to Claim 19 wherein the switch is adapted to be operated via a means for supplying power to the active element of the antenna.

21. An apparatus according to Claim 20 wherein the switch is coupled to the said means for supplying power to the active element of the antenna via a reactance.

22. An apparatus according to Claim 21 wherein the reactance is an inductance.

23. An apparatus according to any of Claims 17 to 22 wherein the switch is a semiconductor device.

24. An apparatus according to Claim 23 wherein the semiconductor device is a gallium arsenide field effect transistor device.

25. An apparatus according to any of Claims 17 to 24 wherein the base station includes means for comparing respective output signals generated by the antenna system in response to the radio signal utilising each of the independent radiation patterns sequentially and producing a difference signal related to the difference in the power levels of the output signals from the antenna systems, means for comparing the difference signal with data representative of the spatial differences between the independent radiation patterns of the antenna system and deriving therefrom an estimate of the direction of the source of the radio signal relative to the base station.

26. An apparatus according to any of Claims 27 to 25 wherein there is included means for deriving an estimate of the separation between the source of the radio signal and the base station.

27. An apparatus according to any of Claims 17 to 25 wherein there is included means for measuring the direction of motion relative to the base station of the source of the radio signal.

28. An apparatus according to Claim 27 wherein there is included means for measuring the rate of motion relative to the base station of the source of the radio signal.

29. An apparatus according to Claim 27 or Claim 28 wherein there is included means for determining the sign and magnitude of the rate of change of the output signal from the antenna utilising one of the independent radiation patterns only thereby to determine the direction and the rate of motion relative to the base station of the source of the radio signal.

30. An apparatus according to any preceding claim wherein the source of the radio signal is a mobile station of a cellular radio communication system and the base station also is a component of the cellular radio communication system.

31. An apparatus according to Claim 30 wherein there is included means for measuring the power of the output signal from the antenna system utilising one of the independent radiation patterns only and comparing it with the power of the signal generated by the mobile station thereby to estimate the distance between the mobile station and the base station.

32. An apparatus according to Claims 30 and 31 wherein there is included means for utilising measured data relating to the distance between the mobile station and the base station, the rate and direction of motion of the mobile station relative to the base station to determine to

which base station neighbouring the said base station the mobile station should be handed over.

33. An apparatus according to Claim 32 wherein the means for determining to which base station the mobile station should be handed over is a microprocessor including a store for data relating to the positions of base stations neighbouring the said base station.

34. An apparatus according to Claim 32 wherein the means for determining to which base station the mobile station should be handed over is a neural network system.

35. An apparatus according to any of Claims 32 to 34 wherein there is included means for initiating the handover of the mobile station to the selected base station.

36. A method of estimating the direction of arrival of a radio signal at a base station substantially as hereinbefore described and with reference to the accompanying drawings.

37. An apparatus for estimating the diredction of arrival of a radio signal at a base station substantially as hereinbefore described with reference to the accompanying drawings.

38. A method of determining to which base station of a cellular radio communication system neighbouring a given base station a mobile station forming part of the cellular radio communication system should be handed over substantially as hereinbefore described and with reference to Figure 3 or Figure 4 of the accompanying drawings.

The Patent Office

18.

Application No: GB 9613531.4
Claims searched: all

Examiner: Dr E P Plummer
Date of search: 13 September 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4D(DAA,DAB,DFBC,DFBB), H4L(LDSL,LDSH)

Int Cl (Ed.6): G01S, H04Q

Other: Online:- WPI, EDOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2281008A	Northern Telecom eg abstract, page 2 lines 6 to 11, page 9 line 18 to page 10 line 11, page 11 lines 1 and 2	1,2,10,12, 15,30,32
X Y	GB2250153A	Siemens Ag eg page 6 lines 9 to 11	1,2,15; 5,6,10,11, 12,30,32
X Y	GB2160735A	The Electricity Council whole document & EP0161940	1,2,15; 5,6,10,11, 12,30,32
X	GB1505434	Siemens Ag whole document	1,2,15
X	WO96/04155A1	Trackmobile Inc eg page 15 line 5 to page 17 line 14	1-4,12,15, 30,31
Y	WO93/12590A1	Array-Comm Inc eg abstract	5,6,10,11, 12,30,32
X	WO88/08140A1	M/A-Com eg abstract, page 23 lines 7 to 21	1,3,12,15

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

The Patent Office

19.

Application No: GB 9613531.4
Claims searched: all

Examiner: Dr E P Plummer
Date of search: 13 September 1996

Category	Identity of document and relevant passage		Relevant to claims
Y	US5465289	E-systems whole document	30
X	US5218367	Trackmobile eg abstract, column 7 lines 60 & 61, column 8 lines 26 to 35	1-4,12, 15,30,31
X	WPI abstract no. 95-099093 & DE4321909		1,2,12,30

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		